LIMITED CIRCULATION

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Agricultural Memorandum No 996

Wind machines for Frost Protection

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Introduction

On many occasions of low surface temperature, especially in late spring, a temperature inversion is formed in which, over a depth varying from a few metres to some tens or even hundreds of metres, the temperature of the air increases with height. Wind machines are designed to exploit this condition by mixing warmer air above the crop with the colder surface air to prevent or ameliorate frost damage to blossom on fruit.

After some 60 years of experiment and development the present day "wind machine" consists essentially of a 10 to 12 m tower supporting one (or possible two) flat blade propellers driven by a ground-mounted motor. The fan is inclined to the vertical and oscillates in the horizontal to mix and distribute the warmer air over a large area. A propellor of some 5 m diameter driven by a 120 hp motor will provide some protection to an area of 3 to 5 hectares.

The degree of temperature lift at the crop height depends on the strength of the inversion. It is claimed that the surface temperature will be increased by 40 to 50% of the "inversion value" - the difference between the temperatures at 1 m and 10 m above the ground; ie for an inversion of $5^{\circ}C$ the temperature will be increased by some 2 to $2.5^{\circ}C$ over the protected area.

Previous studies

Most previous studies into the use of wind machines have been done in Australia and the USA, especially in California and much of the effort has been aimed at providing protection for citrus plantations.

Angus (1962) gives results from a 6-year study at several sites in Australia showing average inversion strength (to 30 feet) of 5.3 to $8.6^{\circ}F$ (some 3 to $5^{\circ}C$) with maximum values of 8.4 to $13.8^{\circ}F$ (some 3 to $8^{\circ}C$). He notes that "in southern California, inversions of $15^{\circ}F$ ($8.3^{\circ}C$) or more are common". He attributes this partly to the particular characteristics of a citrus

plantation and partly to the reinforcement of the radiation inversion by the subsidence inversion being as low as the general level of the citrus area - about 1000 feet ASL. Angus further states that while, in other areas of California, inversions similar to the Australian values are found, these are considered (Goodall et al 1957) to be inadequate for economical wind machine protection.

However, in Bates and Lombard (1978) we find"Hendrich (1974) has quoted Ballard as saying '... if the orchard site consistently shows an inversion with temperatures that are at least 3°F (1.6°C) warmer at the 30 to 50 foot zone than among the trees, a wind machine could be worth trying.'" They go on to argue that mixing the air prevents the fruit or buds cooling to some 2 to 3°F cooler than the surrounding air and also decreases the rate of cooling and so reduces the extent of frost damage.

Ballard, for the same reasons, states that while "a strong inversion is to your advantage, you will gain some protection with weak or no inversions". He admits however that in these circumstances supplemental back-up heating may be required.

Present Investigation

To test the feasibility of frost protection by wind machine in East Anglia we have:-

a. Examined the frequency and strength of inversions measured at Cardington, Bedford.

b. Made measurements of temperature at 5, 30 and 50 feet in a pear orchard near Francham, Norfolk.

1. Observation at Cardington

Temperature measurements at various heights were made using remote recording instruments attached to the cable of a tethered balloon.

The frequency of inversion strength against temperature at 1 m at 0600 GMT during March to May 1957-66 is shown in Table 1 and also graphically in Figure 1.

Data are available for 537 days out of a possible 920 and isothermal or inversion conditions to 9 m existed on 399 of these occasions; average intensity of the inversion was 0.3°C with annual average ranging from 0.2 to 0.4°C.

The probability of an inversion cannot be deduced from these data because of the large number of missing occasions - even accepting that many of the reasons for not flying the balloon would be associated with weather unlikely to produce an inversion.

Consideration of all occasions when temperature at 1 m was 2°C or less (ie leaf temperatures might be at or below 0°C) shows only 7 occasions in the 10-year period when sufficient warming would be available to raise the 1 m temperature to 0°C or above - assuming the warming to be half the inversion value.

2. Observations at Francham

Measurements of temperature were made in a pear orchard at 5, 30 and 50 feet above ground using thermistors and a Grant temperature recorder. The thermistors were exposed in locally designed and constructed screens using plant pot saucers - see Figure 2 - fixed to Dexion arms on a telegraph pole. Temperatures were recorded at hourly intervals from 22 April to 30 May 1983.

It should be noted that this period was entirely frost-free, the lowest temperature recorded at 5 feet was 3.1°C. Nevertheless, there is no reason to believe that the inversion strength would be greater at lower temperatures.

During this period of 38 days, isothermal or inversion conditions between 5 and 30 feet occurred on 34 occasions. The average inversion strength was 0.6°C with a maximum value (when considered at time of lowest 1 m temperature) of 2.0°C. The average of maximum inversion strength, at any time of the night, was 1.0°C with a highest value of 2.5°C.

Between 2 May and 30 May the inversion extended to 50 feet on 13 occasions out of the 29 which had inversions to 30 feet. The average maximum (5 to 50 feet) inversion strength was 1.1°C with a highest value of 2.2°C.

The number of hourly observations with isothermal or inversion to 30 feet varied between 1 and 17 with a mean of 12 hours. Inversions to 50 feet however were much shorter lived with a mean of 4 hours and a maximum duration of 9 hours.

Figure 3 shows approximate temperature profiles during the course of one of the stronger inversion events. While some measure of inversion was present for about 12 hours, it must be appreciated that the inversion will rapidly be broken down by the operation of a wind machine; the extent to which warmer is replaced (and protection still possible) is uncertain.

Frequency of inversions

The evidence of the measurements at Francham, and of the earlier data for Cardington, suggests that "inversion" conditions are fairly frequent occurrences during the spring in East Anglia. It is probable that in sheltered, orchard sites that such inversion conditions will be rather more frequent occurrences than at an "open" meteorological observing site. There is no reason to suspect that 1983 was significantly different from the previous ten years as far as number of radiation nights is concerned.

Conclusions

The use of wind machines for frost protection - ie to keep foliage, blossom or fruit temperatures at or above 0°C - does not appear to be a commercially viable proposition in East Anglia. However, some benefit may be gained by mixing what warmer air is available in terms of improved quality or reduced frost damage. The extent of such benefit is likely to be unique to any one particular situation and it must be up to the grower to balance the possible cash benefits of such reduction on losses against the large capital investment involved in setting up wind machines.

Any comments on suggestions should be addressed to the author.

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September 1983

References

Angus, D.E. (1962) Frost protection experiments using wind machines. Division of Meteorolggical Physics Technical Paper No 12, CSIRO, Australia (Melbourne).

Bates, E and Lombard, P. (1978) Evaluation of temperature inversions and wind machine on frost protection in southern Oregon. Special Report 514, Agric. Exp. Stn. Oregon State University, Corvallis.

Ballard J.K. (-) Frost and frost control in Washington orchards. Extension Bulletin 0634, College of Agriculture, Washington State University, Pullman, Washington.

Acknowledgement

The author is grateful to R Salmon, Hyde Hall, Francham for providing the opportunity to make these measurements - especially for obtaining and erecting the necessary pole and extension to reach 50 feet above ground.

Temperature at 1 metre °C

$\Delta [T_{(9m)} - T_{(1m)}]$ °C	≤-3.0	-2 to -2.9	-1 to -1.9	0 to -0.9	0.1 to 1.0	1.1 to 2.0	2.1 to 3.0	≥3.1	TOTAL
≤-0.1	1	2	1	2		4	12	116	138
0.0 to 0.9	9	8	10	18	12	20	30	262	369
1.0 to 1.9	4	2	3	3	2	3	2	7	26
2.0 to 2.9				1				1	2
≥3.0			1			1			2
TOTAL	14	12	15	24	14	28	44	386	537

No inversion

Table 1.

Frequency of inversions at Cardington, Bedford

FREQUENCY AND INTENSITY OF INVERSIONS AT 0600

CARDINGTON, BEDFORD MARCH to MAY 1957-66

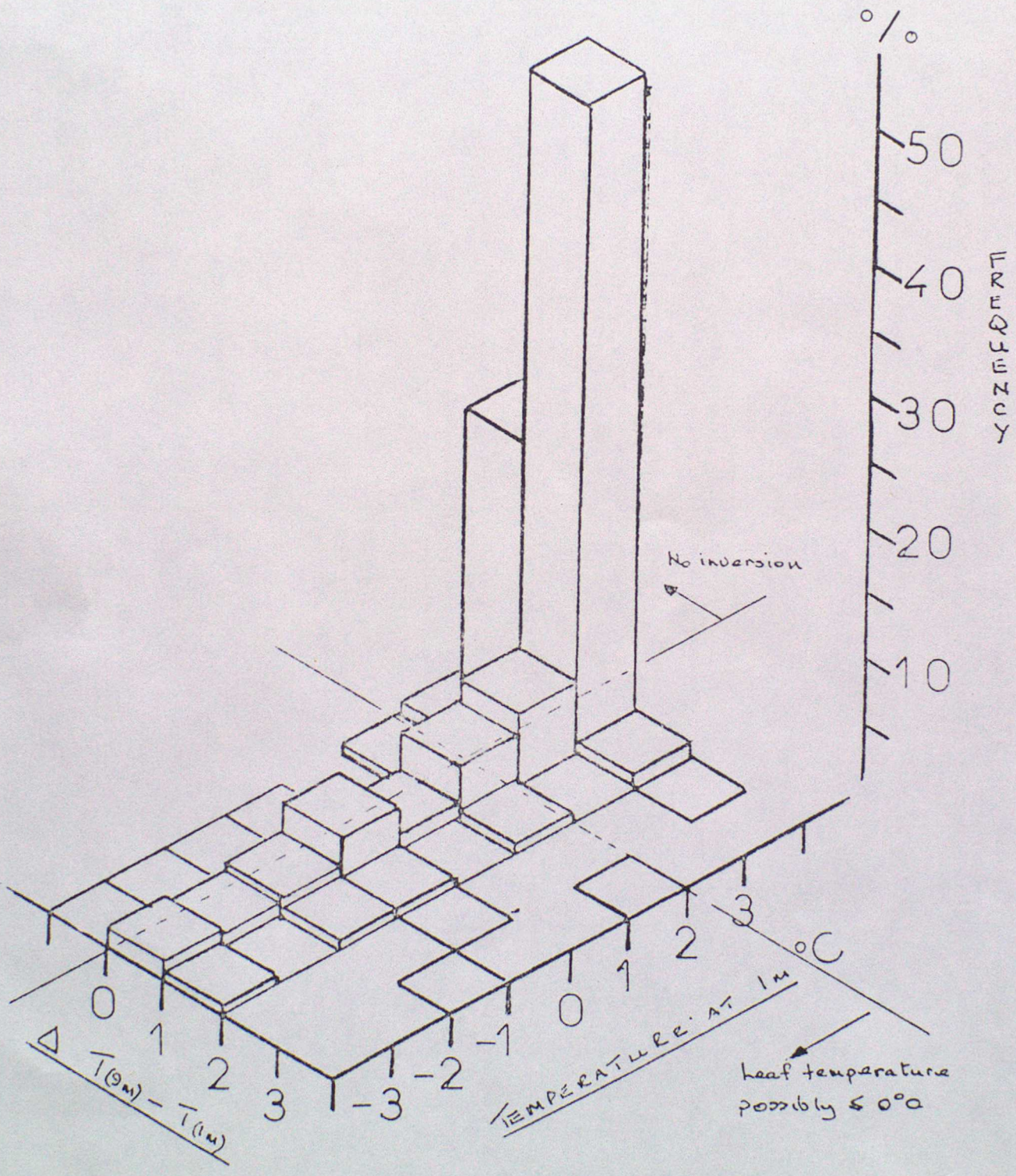

FIGURE 1.

Diagram to indicate construction of "Saucer Screen"

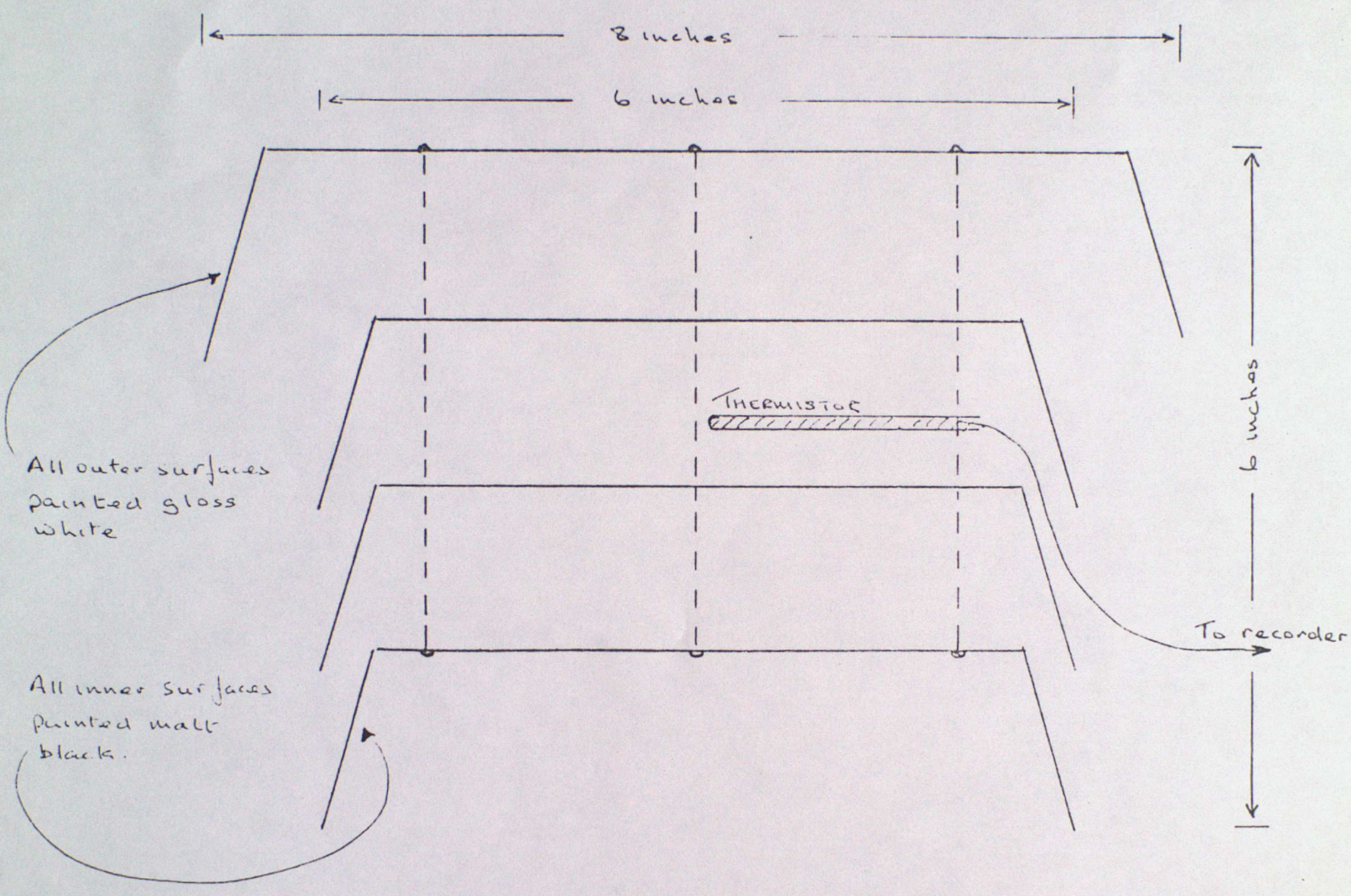

FIGURE 2.

APPROXIMATE TEMPERATURE PROFILES DURING AN INVERSION EVENT

FRANCHAM 21 - 22 MAY 1983

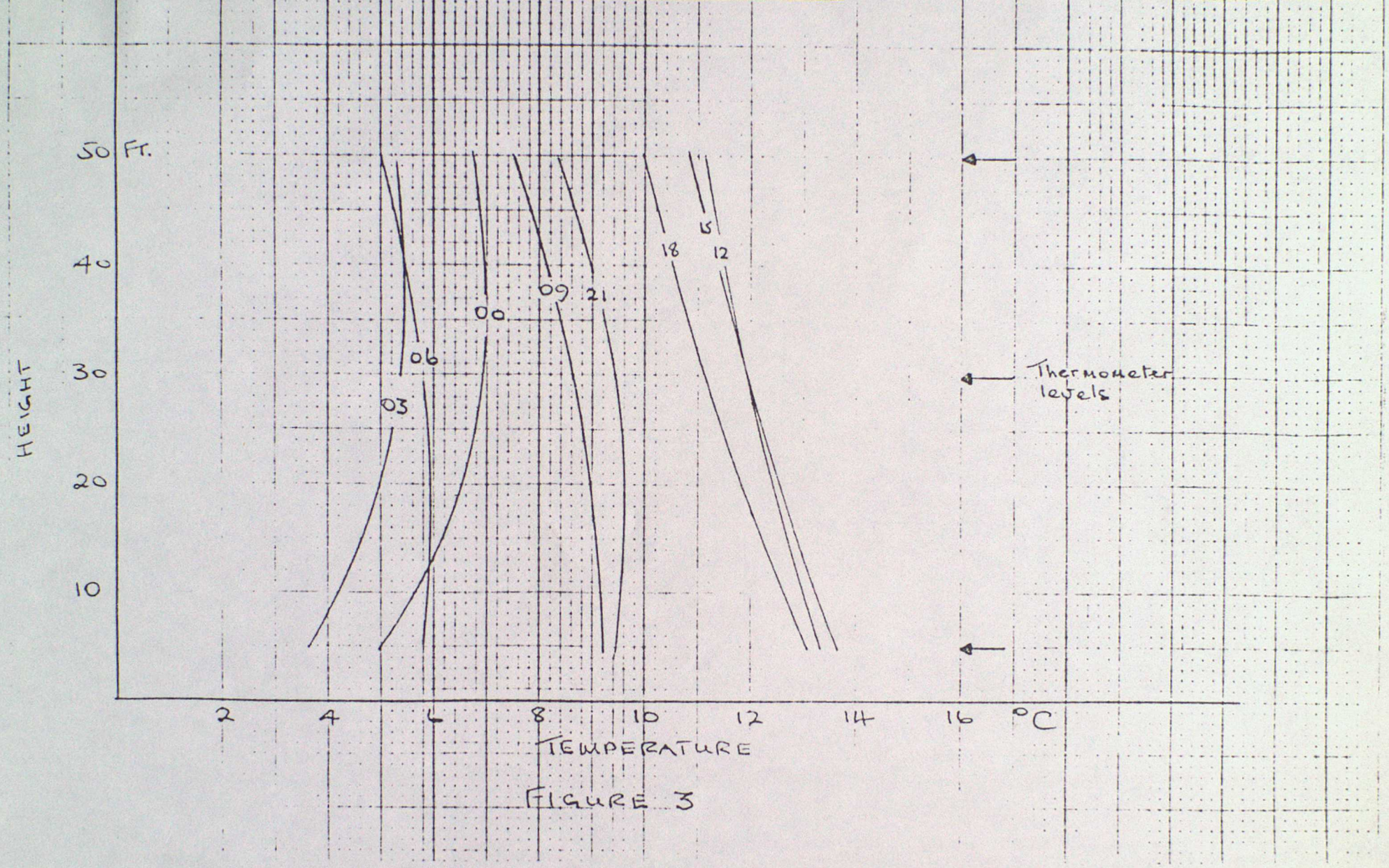

FIGURE 3